AN OPERATIONAL MULTI-SENSOR GEOCODED PRODUCTION SYSTEM FOR EARTH RESOURCES SATELLITE IMAGES

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ABSTRACT

It is highly demanded to integrate the remote sensing images with other spatial data in geographic information systems, hence, an efficient and reliable geocoded production system is a must for a ground receiving station or a data provider of remote sensing satellite imagery. From the operation's point of view, most of the commercial packages are not quite suitable for our specific need in massive production, simply because their structure is dedicated to individual application. The objective of this paper is thus to design an, indigenous, workorder-based multi-sensor geocoded production system in a PC-Internet environment, called the MSGPS system. The features of the proposed system include (1) automatic workflow control, (2) low cost of hardware and maintenance, (3) high production throughput, and (4) possible multi-sensor expansion. The major functions of the proposed system are (1) web querying and ordering, (2) workorder management, (3) orbit modeling and quality control, and (4) ortho-rectification kernel. Preliminary test results indicate that the proposed system can reach high performance and geometric quality with low cost.

1. INTRODUCTION

The most important feature of an earth resource satellite image is that it provides geometric and radiometric information for the application of spatial data analysis. Thus, it is highly demanded to integrate the remote sensing images with other spatial data in geographic information systems. For a ground receiving station or a data provider of remote sensing satellite imagery, such as the Earth Resource Satellite Ground Receiving Station under the Center for Space and Remote Sensing Research (CSRSR), an efficient and reliable geocoded production system is a great demand.

Many research efforts on geometric correction of remote sensing images, such as SPOT [1][2][3], EROS [4][5], IKONOS [6], Air Photo [7], AMSS [8], ERS [9][10], etc., have been going on for more than 10 years in CSRSR. From the operation's point of view, most of the commercial packages are not quite suitable for our need, simply because their structure is dedicated to individual application. The objective of this paper is thus to design an, indigenous, workorder-based Multi-Sensor Geocoded Production System (MSGPS) in a PC-Internet environment. The workflow of the MSGPS system is depicted in Figure1.

The major functions of the proposed system are (1) web querying and ordering, (2) workorder management, (3) orbit modeling and quality control, and (4) ortho-rectification kernel. A www database server is the core to realize these functions. The original raw images are clipped as scenes of images and stored in the database. Users can query the original raw images from the web and order a geocoded product from the web. A workorder is thus initiated and stored in the database. An operator is then informed to process the workorder from the workorder management interface. The parameters setup for geocoding process are automatic, and accordingly, the training of operators for the process could be minimized. When a process is completed, new product records are inserted into the database automatically for update. Any users can thus query and order those geocoded products from the internet.

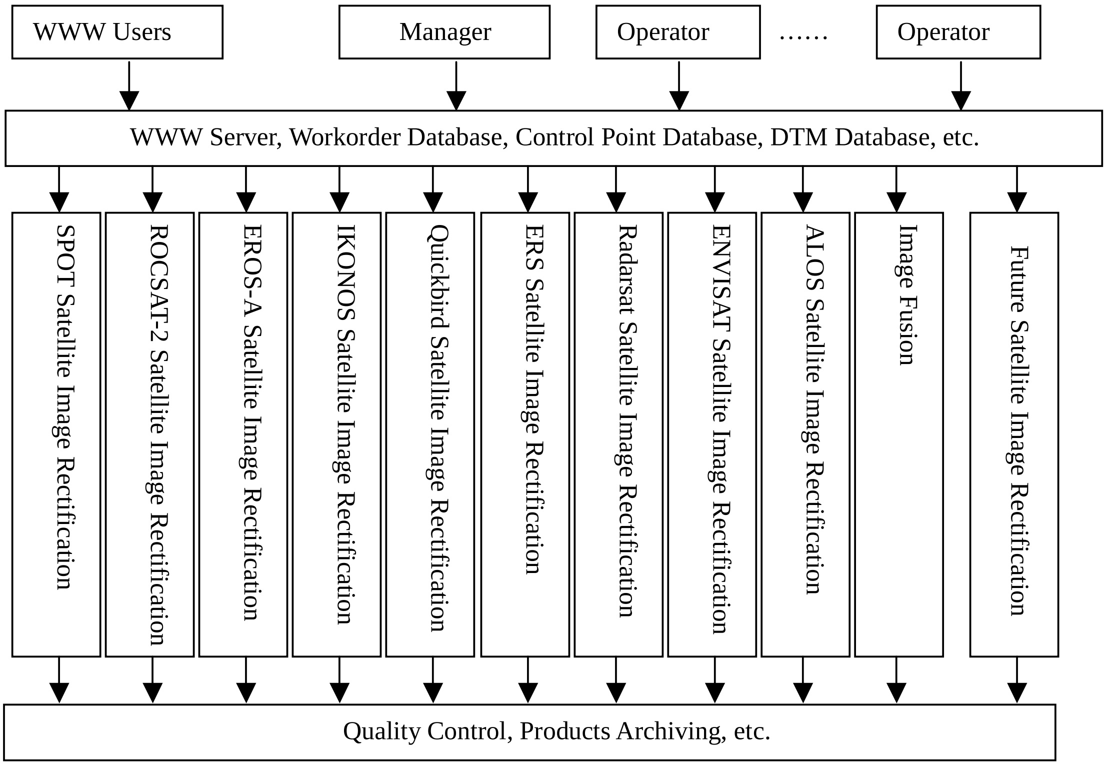

Figure 1, Workflow of the MSGPS system.

The production throughput of the proposed system mainly depends on the efficiency at the orbit modeling and the ortho-rectification stage. In the orbit modeling, a ground control point (GCP) database incorporating with three-dimensional geographic locations and image template is necessary. A user-friendly graphic user interface for marking GCPs and checkpoints (CKP) is implemented. The automatic image matching technique is also implemented to reduce the operator's workloads. The control point database also serves for geometrical quality assurance check. In ortho-rectification, an efficient and yet rigorous algorithm is performed to rectify a contiguous segment of satellite imagery with the minimum number of GCPs and to ensure the best geometric quality. In addition, the digital terrain model (DTM) database is the primary element for the purpose of terrain relief correction in ortho-rectification.

The operation environment is adopted on a personal computer, thus the cost is reduced in comparison with a high-end workstation, while keeping comparable performance. In the meantime, the system retains the flexibility of expanding the processing for future earth resource satellites. The core software for multi-sensor geocoded production includes the optical images, such as SPOT, EROS, IKONOS, ROCSAT-2, and Quickbird. The system reserves the room for processing the SAR images from the ERS, ENVISAT, RADARSAT, and ALOS in the future.

2. METHODOLDGY

The major functions of the MSGPS system are (1) web querying and ordering, (2) workorder management, (3) orbit modeling and quality control, and (4) ortho-rectification kernel. Detail descriptions of those functions are described in the following.

■ Web querying and ordering

There are more than 800 thousand of raw scenes archived in CSRSR during a ten years of reception since June 1993. In order to achieve the best performance of querying and ordering for WWW users, we utilize an Oracle database under the Linux operation system using a dual XEON CPU of a Compaq EvoW6000 Workstation. Comparing with any high-end Unix workstation, the maintenance fee is affordable and much less expansive.

A well-known web-programming language called "Java Server Page" is used for coding the function of querying and ordering on the internet. The major concerns about the chosen programming language are the security and the portability. The security of order transaction is a requirement in such an opening network. From the maintenance's point of view, the portability to different operation system of a server is also important. Furthermore, from the user's point of view, the web-browsing result on the client computer should be the same now matter what kind of browser is used. The Java Server Page provides such needs.

■ Workorder management

The programming language used for workorder management interface is the Microsoft Visual Basic .Net (VB.NET). The interface between the Oracle database and VB.NET is the ADO.NET driver, which provides off-line and multi-user database access. It is especially suitable for the internet environment and a multi-operator production system. When a user request of ortho-image product is initiated, a workorder is created and stored in a workorder database, which includes all information about the selected raw image(s) and required parameters about the product. The idea of workorder control is thus to guide an inexperienced operator for geocoding process of satellite images without any parameter setup for the product. The major workload of an operator is, accordingly, reduced and minimized at the stage of GCP marking and the quality control. The final product archive is also implemented, which provides an opportunity for other user request of the same product to avoid a duplicate geometric process.

In case the internet is disconnected unexpectedly, the Microsoft Access database may be adopted to handle local workorder without any delay of product delivery. It means that the operator can also create a local workorder for ortho-image production from the workorder management interface. Some functions are necessary, such as import raw scene information, query and select the input raw image(s), parameter setup for the product(s), product archiving, and workorder creation, etc.

■ Orbit modeling and quality control

The bottleneck of an orthoimage production is at the phase of manual GCP marking for orbit modeling. Hence, it is essential to have a user-friendly graphic interface to assist the operator in searching and identifying a GCP from its conjugate image point. The GCP database includes not only its three-dimensional coordinates but also an image template, which is useful for manual identification and automatic image matching. In other words, the whole GCP marking procedure is actually a semi-automatic process to accelerate the whole geocoded production.

In the meantime, the graphic user interface is also migrated to the final product quality control, called QCP marking. The graphic user interface is coded using the popular ESRI ArcObjects library, as the concept of GIS layer is useful for manual CP marking. For the purpose of manipulating the image, such as the zoom in, zoom out, and searching, an image pyramid was built at the first time entering the stage of GCP/QCP marking. The time required for producing the image pyramid depends on the image size.

In the marking of a GCP, we can add a digital base-map or a digital topomap onto the GCP's image template for searching and identifying its conjugate image point. Once a GCP is identified, the orbit parameters can be updated and we can predict the image location for any selected GCP. The GCP database is identical to the checkpoint database, except that the checkpoint is not used in the orbit parameters adjustment. In case a sufficient number of GCPs and checkpoints are identified, the root-mean-square error (RMSE) of all checkpoints will serve as an indicator for the accuracy of final orbit modeling.

At the phase of quality control, a number of checkpoints are marked on the produced orthoimage. The RMSE of all checkpoints depicts the accuracy of final product to check its geometric quality. In case the RMSE is less than the pre-defined accuracy requirement of the sensor, the product is ready for archiving and delivery.

■ Ortho-rectification kernel

It is known that the geometric quality of an orthoimage product relies on five major factors. Those five major factors are the accuracy of GCP, the measurement error of GCPs on the image plane, the accuracy of DTM for relief correction, the function of model in orbit adjustment, and finally the algorithm for ortho- rectification. The GCP and DTM are all the same for every sensor and we assumed the error of manual measured image coordinate is minimized. Hence, the other two factors dominate the geometric quality of a product.

As the MSGPS system is designed for multi-sensor, the ortho-rectification algorithm adopted for each sensor is independent. It is especially different from an optical sensor to a SAR one. In this paper we focus on the SPOT system and all demonstration are based on this system.

In orbit adjustment, the corrections of satellite position and attitude parameters are described as a function of time using the 2^{nd} and the 3^{rd} order of polynomial function, respectively. The on-board ephemeris data about satellite position and attitude are used as initial value. Thus, the number of GCP could be minimized while still preserving the required accuracy. The GCPs are used to correct the systematic error of the orbit and a *least-squared prediction* technique is applied to remove its random error, [11][12]. The proposed orbit adjustment method is suitable for any kinds of push-broom sensors, such as EROS-A [4][5], IKONOS, and Quickbird, provided that the satellite on-board ephemeris information is available.

In ortho-rectification phase, as the traditional pixel-by-pixel bottom-up method for ortho- rectification is time-consuming, a modified *patch back-projection* method is proposed, [13]. At first, in the area of product we divide its corresponding DTM into many large equal-grid patches. Each DTM patch, about four square-kilometers, is analyzed to find its maximum and minimum height. Secondly, the bottom-up method is applied on the corners of a DTM patch using its maximum and minimum height, respectively. At this moment, we have two sets of four ground points and four image points for each patch, one for the maximum height and the other for the minimum height. A six-parameters transformation coefficient for each set can thus be estimated. That means, for any ground point inside the DTM patch, two initial image points can be estimated using the above two sets of transformation coefficient. Finally, since the height of the ground point is between the maximum and the minimum height, the exact image coordinate for the ground point is a linear interpolation between those two initial image points. The weighting for interpolation is estimated from the difference of its exact height to the maximum and the minimum height.

The proposed algorithm for ortho-rectification is efficient and yet preserving the geometric quality of the product. An evaluation about the difference between the traditional bottom-up method and the *patch back-projection* method has investigated. [13] The standard deviation of the difference is less than 0.15 pixels when the range of DTM is less than 2000 meters. The difference is negligible in comparison with the random error in orbit modeling.

3. CASE STUDY

In this section, the GUI interface of the proposed MSGPS system is illustrated. A benchmark test for the proposed system is evaluated on three ways, i.e., the efficiency about the web querying, the efficiency about the designed CP marking interface, and finally the efficiency and the accuracy of ortho-rectification kernel.

Table 1 shows the specification and the test results of the test data set, in which three kinds of image mode for SPOT-5 satellite are evaluated. The personal computer used in this study is based on an Athelon 3.0 GHz CPU with one GB memory and a 7,200 RPM hard disk. Before further exploration about the test results, the properties of the basic database, that is the GCP and DTM, used in the MSGPS system is described in the following.

Table 1, Specification and test results of case studies.

Case	1	2	3
Satellite/Sensor	SP5/G2J	SP5/G2B	SP5/G2T
Image Mode	XS	PLA	Supermode
Acquisition Date	2003/3/15	2003/3/15	2003/3/15
Resolution (m)	10	5	2.5
No. of Bands	4	1	1
Raw Scene Image Size	6000 x 6000	12000 x 12000	24000 x 24000
No. of Inputs	8	8	8
Time to Build Image Pyramid	2.5 Min.	5.0 Min.	25.0 Min.
No. of GCP	9	9	9
No. of CKP	21	21	21
RMS of GCP	6.9 / 5.28	7.06 / 7.6	4.38 / 7.74
RMS of CKP	9.61 / 10.1	7.88 / 7.89	7.83 / 6.08
Time for CP Marking	40 Min.	50 Min.	60 Min.
Ortho-Image Size	27,500 x 12,000	55,000 x 24,000	104,000 x 37,200
Ortho-Image Ground Range	275 Km x 120 Km	275 Km x 120 Km	275 Km x 90 Km
Image Volume	1320 MB	1320 MB	3868.8 MB
Time for Rectification	51.35 Min.	69.28 Min.	242.96 Min.
No. of QCP	40	40	50
RMS of QCP	12.96 / 11.85	8.27 / 9.52	7.64 / 9.23
Time of QCP Marking	40 Min.	40 Min.	70 Min.
Total of Time	2 Hrs. 16 Min.	2 Hrs. 51 Min.	7 Hrs.

*RMS in units of meters

- GCP

The ground control points were digitized from 1:5,000 and 1:10,000 scale of base map. The accuracy from those two sources of GCP is about 5 meters and 10 meters, respectively. Most of the 1:5,000 base maps are located at the west side of Taiwan and surrounding the island. Each GCP has a corresponding image template and ground feature description for manual recognition, with the ground sampling distance (GSD) of 10 meters.

The test data set is located at the east side of Taiwan and 90 % of the land area is mountainous with height range from 0 to 3800 meters, as shown in the search window of Figure 4. Most of the available GCPs were digitized from the 1:10,000 scale base map with 10 meters of accuracy. Additionally, the south side of the image is quite cloudy that makes the GCP marking very difficult with poor distribution. With the adopted orbit adjustment method the problem could be overcome while preserving the best accuracy.

- DTM

The DTM were manually measured from aerial photography under the analytical stereoplotter with 40 meters of grid size. The accuracy of DTM is about 10 meters and 20 meters for 1:5,000 and 1:10,000 scale of base map, respectively. Again, the error of used DTM in the test area is mostly around 20 meters.

- Workorder management interface

Figure 2 illustrates the designed workorder management main interface, in which the status, the starting date, the used PC, etc., for all workorder are displayed. All operators can thus understand which workorder is waiting, importing images, GCP marking, QA CP Marking, rectifying, or archiving, etc. As shown in Figure 3, a multi-tabs frame guides every step of an ortho-rectification workorder. The procedure of a workorder is, then, constrained to process step by step. The major training efforts for an inexperience operator lie on the training of CP marking. The work content for an operator is thus minimized and the training cost is also reduced as well.

- Web querying

A comparison about the proposed web-querying scheme to the old one is evaluated. The old scheme utilized CGI application under a DEC Alpha workstation. After a large quantity of test on querying using the same condition, the proposed scheme is about 8 times faster than the old one. It clearly demonstrates that the proposed scheme is not only in low hardware cost but also more efficient in querying.

- Manual GCP marking interface

Figure 4 illustrates the GCP marking interface. The interface is also applied to the work of QCP marking. In Figure 4, all 8 raw images for case study 1, which comprise a long segment of 450 km stripe, is carried out for orbit modeling at the same time. A *search window* displays all input images necessary for the workorder. The *image view* that overlay with all available GCPs is designed for CP marking. An *image template* of the selected GCP could also be displayed to aid human recognition. A *table-list* of orbit adjustment result depicts the error and the status of the assigned GCPs and the selected CKPs. One can select a GCP either from the list or from the image view.

From Table 1, for all case studies, 9 GCPs are marked for orbit modeling and 21 checkpoints are measured for accuracy analysis. Finally, the RMSE of the checkpoints are all less than 10 metes in X/Y axis. The time spent in CP marking for all three cases are less than one hour. As the image template has a GSD of 10 meters, the ambiguity in CP marking is increased when the image ground resolution is higher. Consequently, it takes more time with human recognition in Supermode image. Since the accuracy of current used GCP is mostly in 10 meters, the accuracy of orbit modeling result is expected. From the experimental results, it demonstrates that the proposed orbit adjustment method is accurate, reliable and stable for a long stripe of SPOT images even though a small amount of GCPs is available.

- Ortho-rectification

After orbit modeling, the ortho-images are produced. The time taken for all three case studies are depicted in Table 1. On average, a 15 MB to 25 MB of image volume is created in one minute. Finally, in quality control phase, 40 QCPs are measured for case 1 and 2, and 50 QCPs for case 3. The RMSE ranges from 7.6 to 13 meters. Again, since the accuracy of current used GCP and DTM are about 10 meters and 20 meters, respectively. The accuracy of the generated ortho-image is acceptable. In order to verify the global geometric quality of the produced ortho-image, we overlay a road vector data, which was digitized from 1:5,000 scale of base map, onto the generated SPOT-5 Supermode ortho-image. As shown in Figure 5, the road vector is quite consistent with the road feature in the ortho-image. Figure 6 depicts the error vector plot of the QCPs in quality control phase for case study 1. It is clear that the generated ortho-image does not have any systematic errors. From the above demonstration, we can see that the proposed patch back-projection method for ortho- rectification is efficient and accurate.

In summary, the total of process time for each case, from importing image to final product archiving, takes from 2 fours to 7 hours, depending on the requested ortho-image size. Comparing with the current geocoding system of PPGS/MATRA, French, the total of time taken for such a long segment of SPOT 1~4, XS or PLA images, is more than 8 fours. As the PPGS system has to ortho-rectify each input image separately, and then mosaics them together. The time taken in CP marking and heavy manual operation dominates the total process time. The reducing of workload and the improvement of efficiency is encouraging for the proposed MSGPS system.

4. CONCLUSION

In this paper, we propose a multi-sensor geocoded production system for the purpose of generating large quantity of ortho-rectification products. From the demonstrated case studies, we conclude the following significance features of the proposed MSGPS system. They are:

1. The hardware and maintenance cost are reduced significantly, due to a low-end personal computer is employed. The more personal computers are utilized, the more production throughput could be achieved with low hardware cost and maintenance fee.
2. The efficiency of web-query is about 8 times faster, comparing with the old scheme. A workorder can be generated automatically when a user request has ordered from the web, or created manually when the

web connection is not available to avoid the delay of product delivery.

3. With the robust and accurate orbit adjustment method, a user friendly GCP and QCP marking interfaces lead to a great improvement in the labor-intensive workload.
4. An inexperienced operator is sufficient for the process of a workorder. The training cost is thus reduced as well.
5. The produced ortho-images for SPOT-5 XS, PLA and Supermode images have an accuracy of 13, 10 and 10 meters, respectively. The expected accuracy is based on a long stripe of image that is modeled with only 9 GCPs with poor GCP distribution and the used GCP and DTM have a certain degree of error.
6. The proposed MSGPS system is cost-effective comparing with any commercial package or any high-end dedicated ortho-rectification system.

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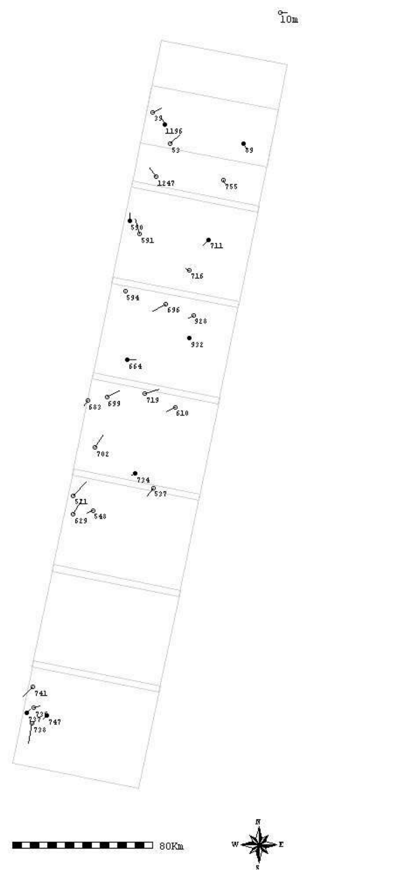

Figure 6, Error vector plot of orbit modeling for case study 1.

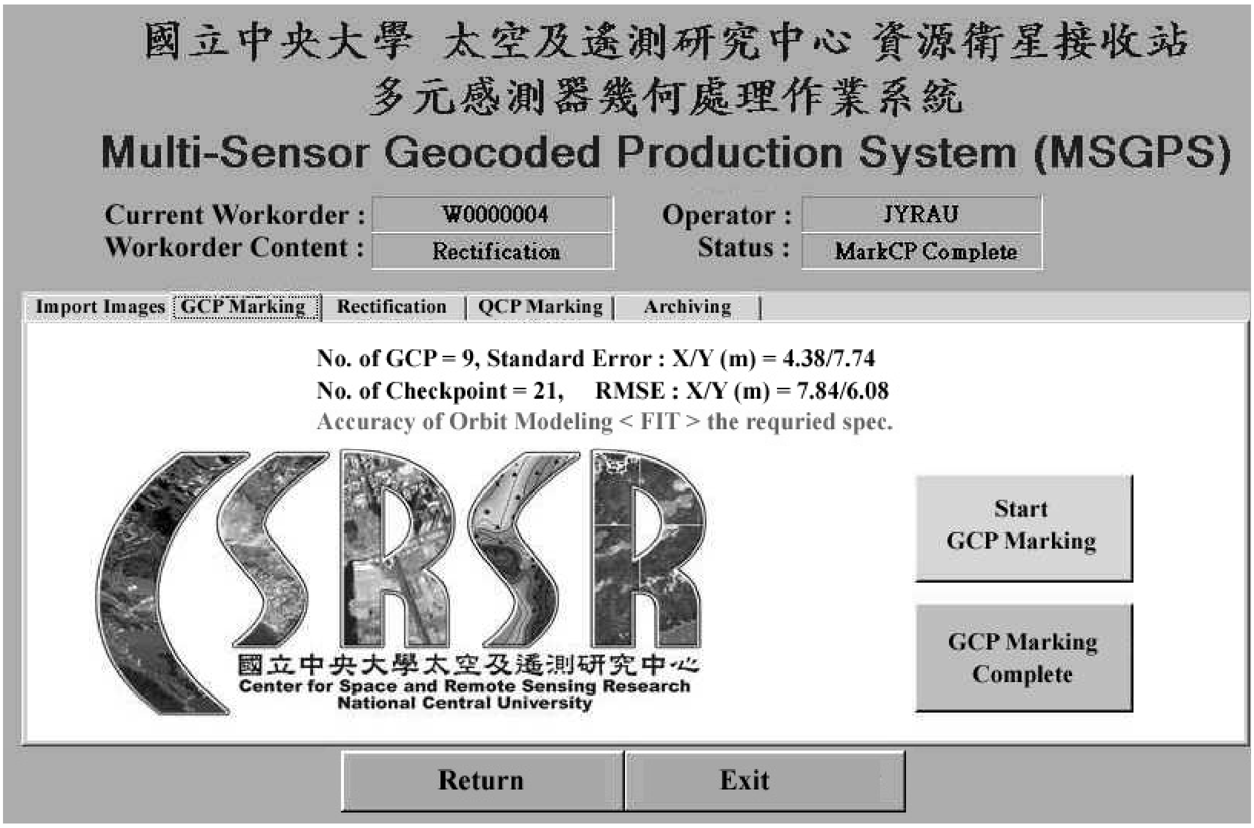

Figure 2. Main workorder form of the MSGPS system

Figure 3. The multi-tabs form is designed for the process of a workorder.

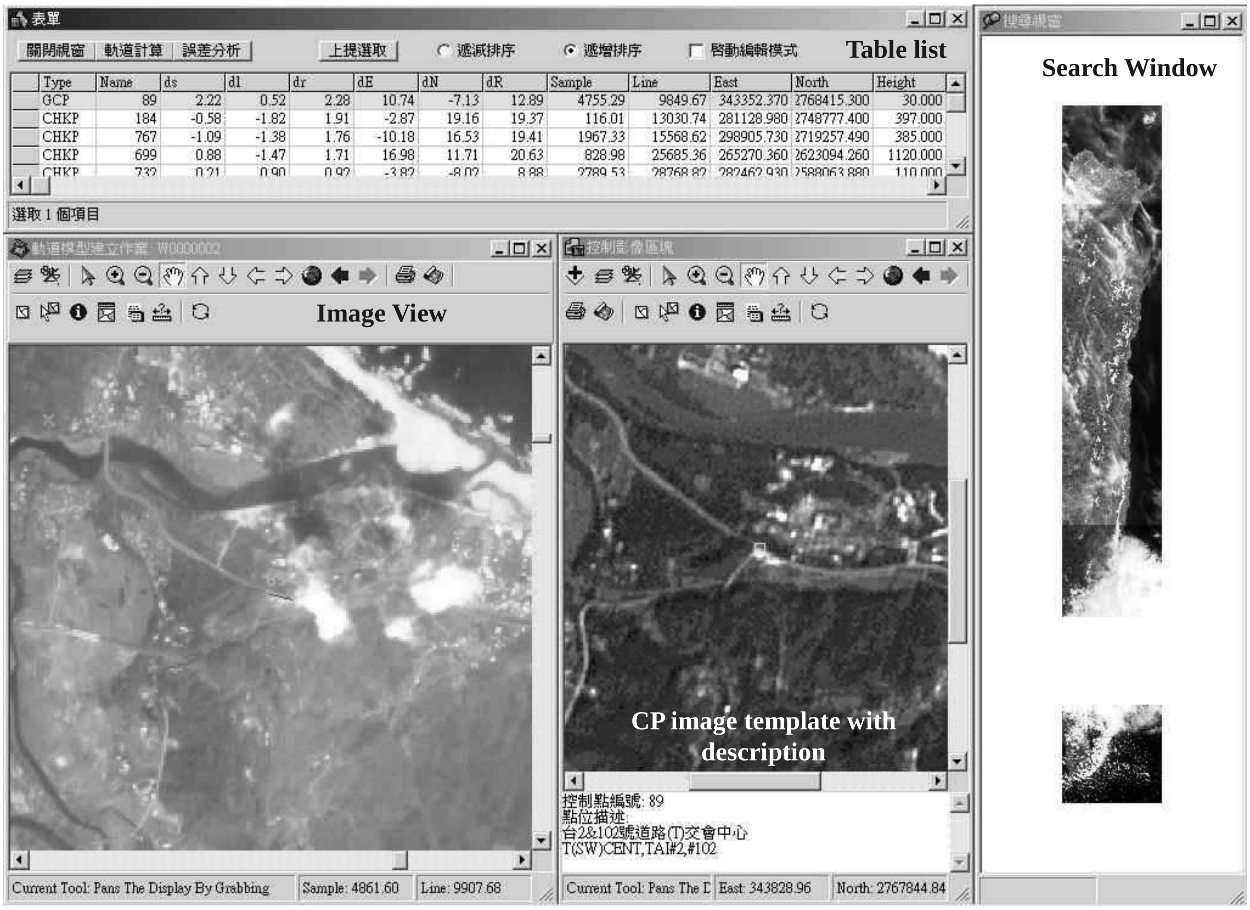

Figure 4. The proposed GCP and QCP marking GUI interface.

Figure 5. The generated SPOT-5 Supermode image overlay with road vector data.